50 Years of Antiprotons

An Anniversary Symposium

LBNL, October 28-29, 2005

Antiproton - Proton Colliders: Technical Challenges

Lyndon Evans

Proton - Antiproton Colliders

In the mid 1960's, Carlo Rubbia proposed to use the yet-to-be-built SPS as a proton-antiproton collider in order to transform the 300 GeV machine to an equivalent fixed-target machine of 2×10^{14} eV!

In order to achieve this, it was first necessary to develop the technology for the production, accumulation and cooling of intense antiproton beams.

Joseph Liouville (1809 – 1882)

Beam Cooling

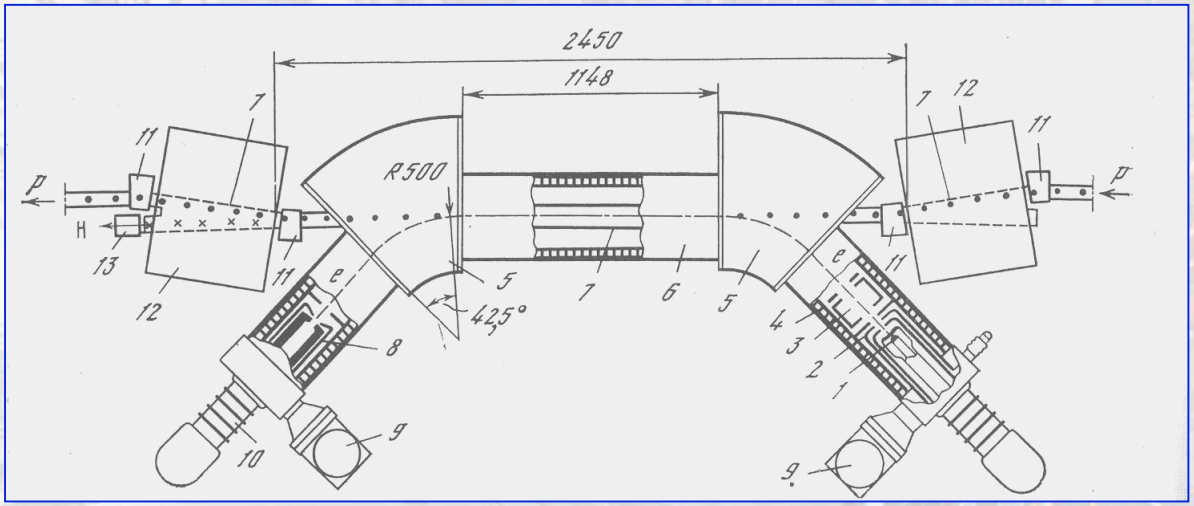
Liouville's theorem states that the phase space density of a particle beam cannot be changed under the action of conservative forces if the beam is considered to be a continuous medium.

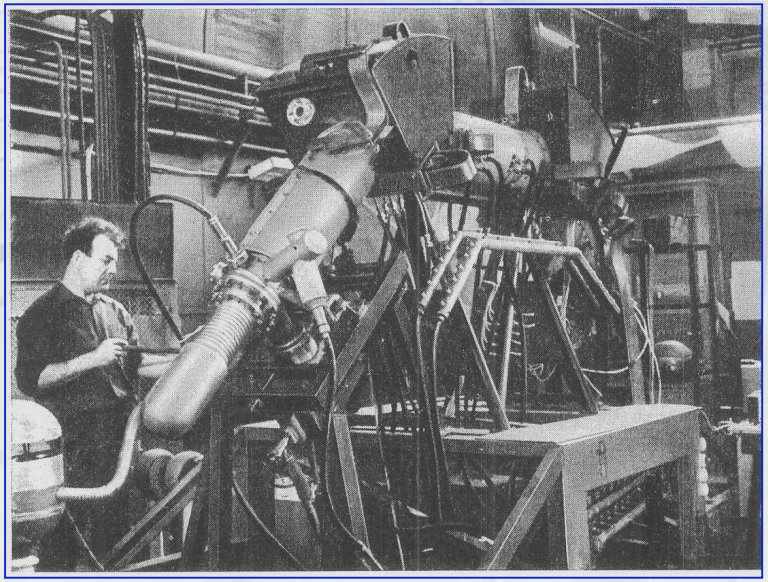
Electron beams are naturally cooled by the emission of synchrotron radiation.

In the 1960's, Budker proposed the cooling of protons by their interaction with a cold electron beam (non-conservative) Coulomb collisions.

In 1972 (from work done in 1968), Van der Meer discovered the principle of stochastic cooling, which makes use of the fact that the beam is not a continuous medium.

Electron Cooling





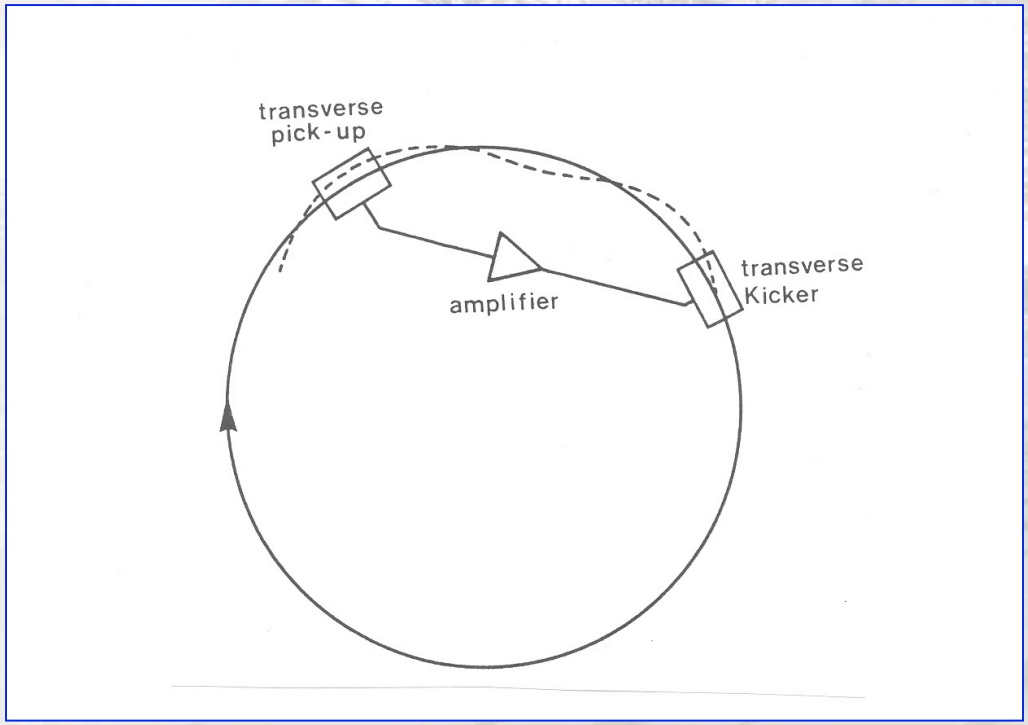
Electron Cooling

- Fast

- Most suited for low- β beams. Very effective for heavy ions and will be used to cool the Pb ion beam for LHC. Until recently it was not possible to cool antiprotons produced at high energy.

- Effective at cooling beams that are already cool. Not good for cooling antiprotons directly from production target.

Stochastic Betatron Cooling



$$\bar{x} = \frac{\sigma_s}{\sqrt{N_s}} \quad \frac{1}{\tau} = \frac{W}{2N}$$

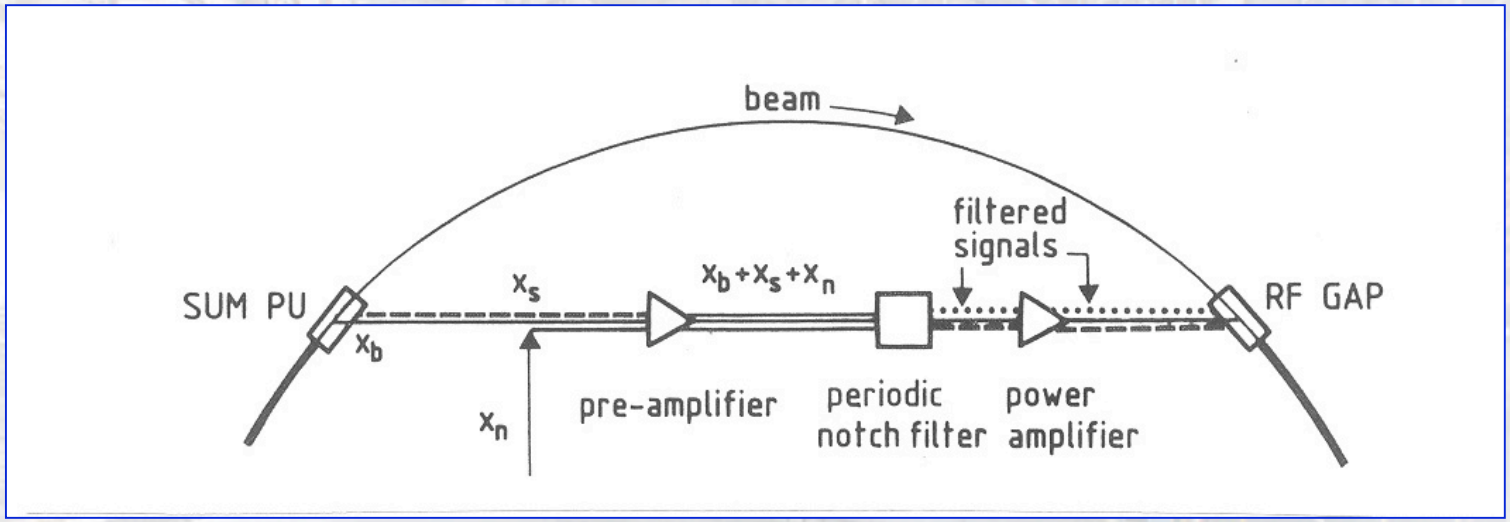
No mixing from pickup to kicker

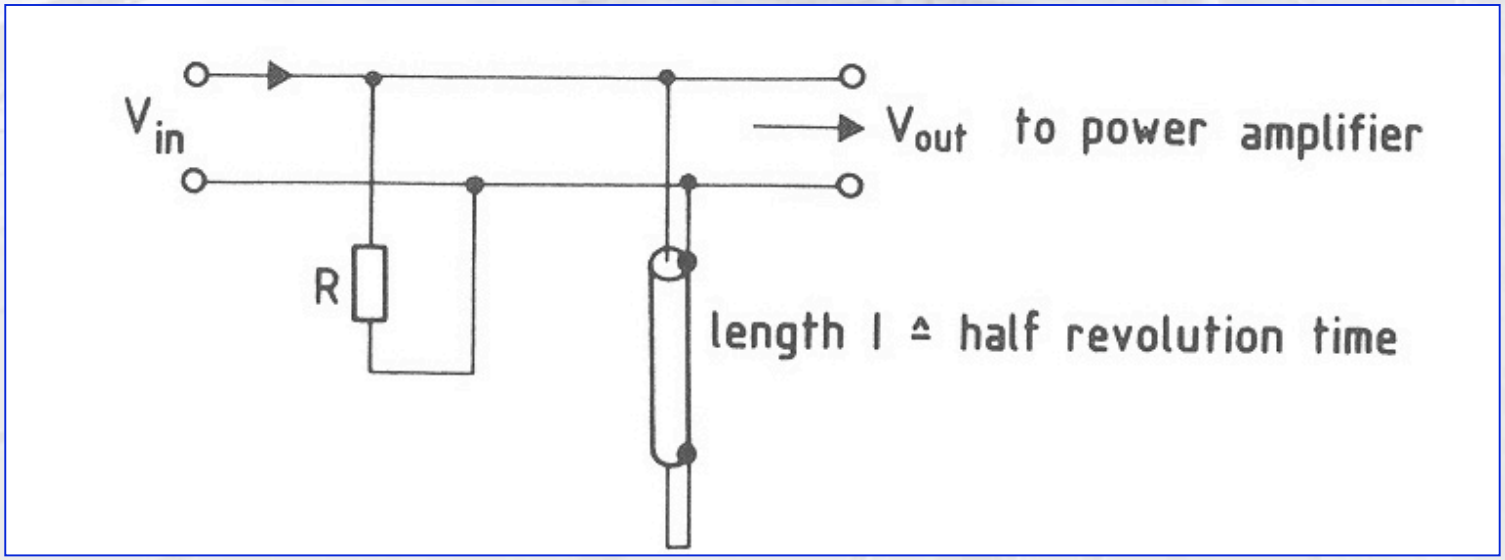
Good mixing from kicker to pickup

The Intersecting Storage Rings (1971-1984)

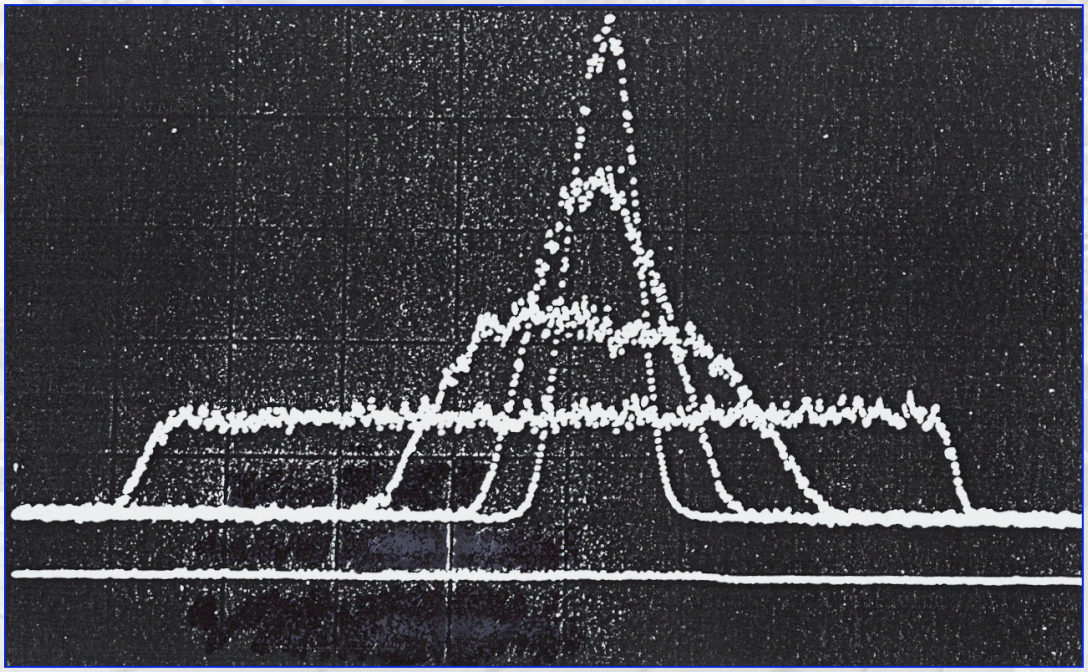
- First hadron storage rings
- First observation of Schottky noise
- First demonstration of stochastic cooling

Momentum Cooling with Filters





Momentum Cooling in ICE

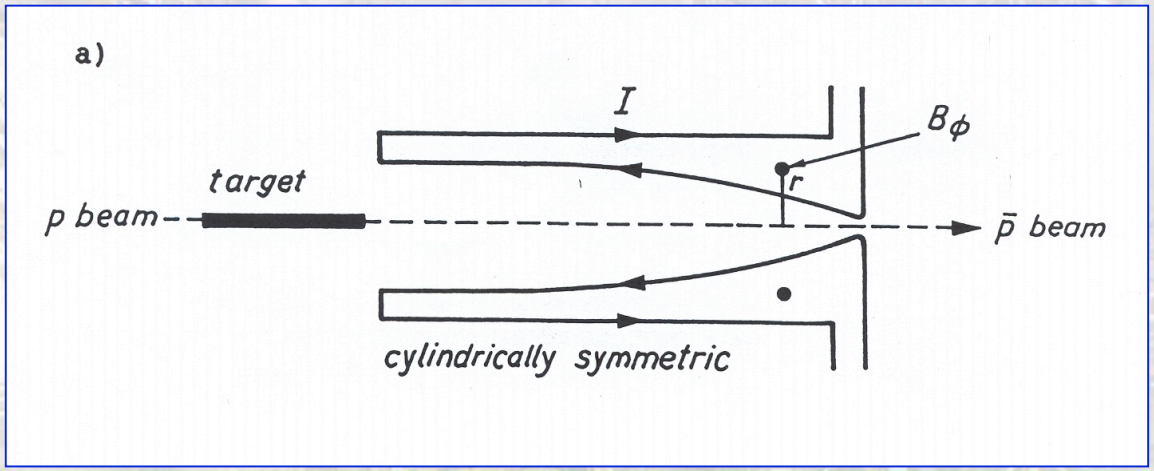


Schottky scan after 1, 2 and 4 min.

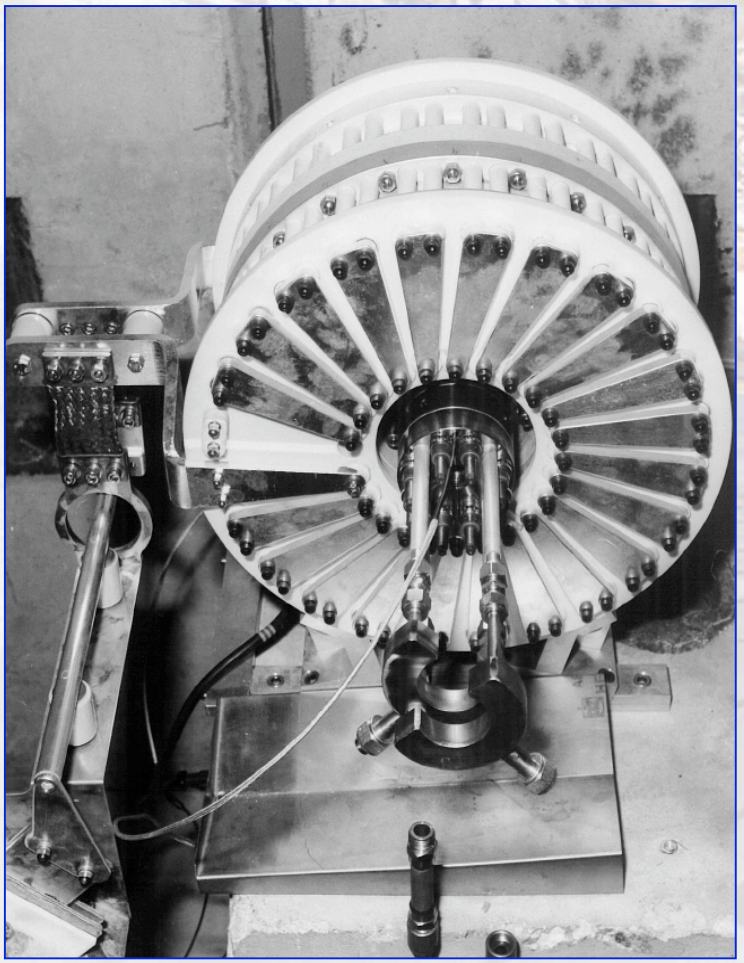
Signal height proportional to the square root of density and width proportional to Δ p/p.

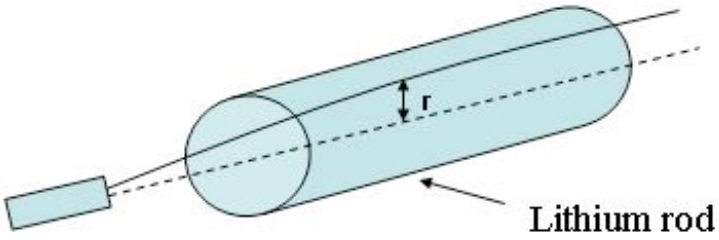
The Antiproton Accumulator

Antiproton Collection with Horn



With Lithium Lens





$$B_\phi \propto \frac{\pi r^2 J}{r}$$

FNAL Performance

- Present pbar stacking rate of > 1E11 per hour
- Stochastic cooling in 4-8 GHz band increases the 6D phase space density by about 1E9.

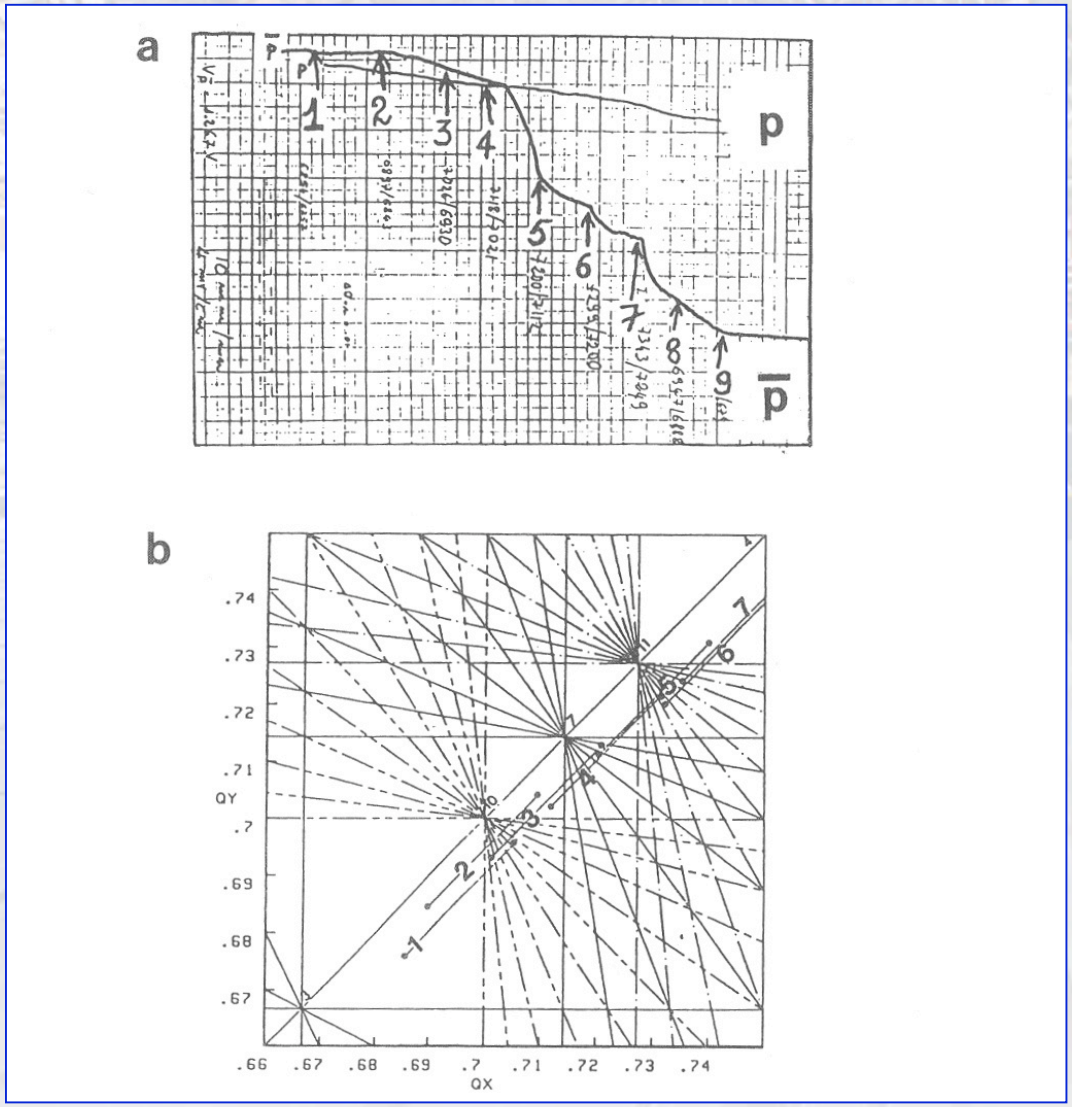
Proton – Antiproton Colliders

The acceleration and storage of intense proton and antiproton colliding beams create many problems which have to be resolved in order to produce luminosity.

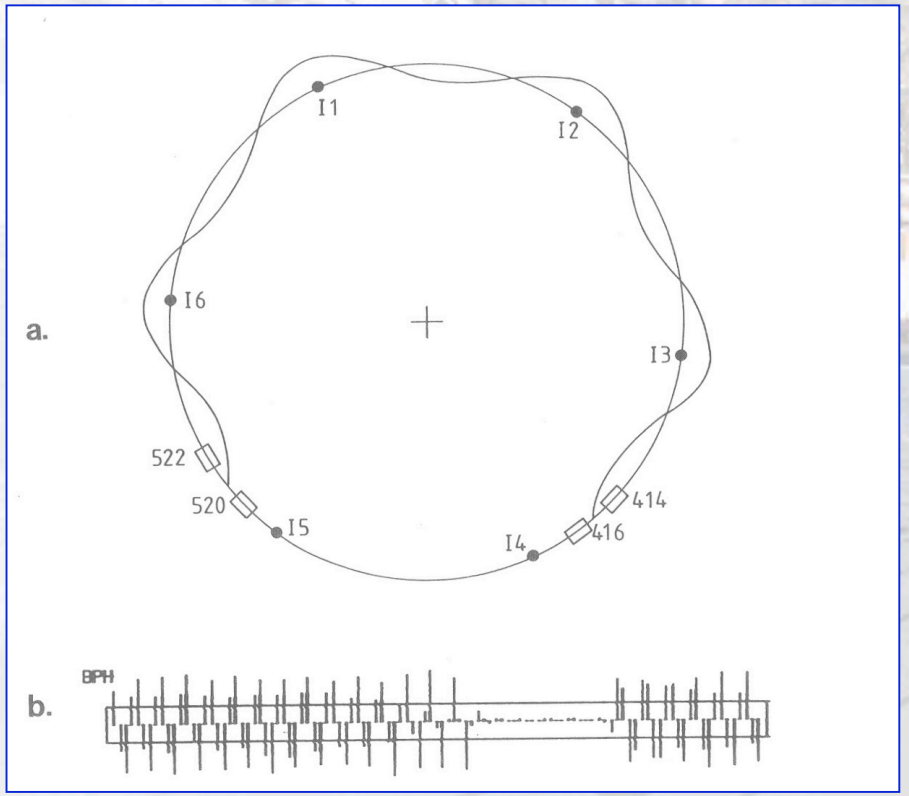
They include:

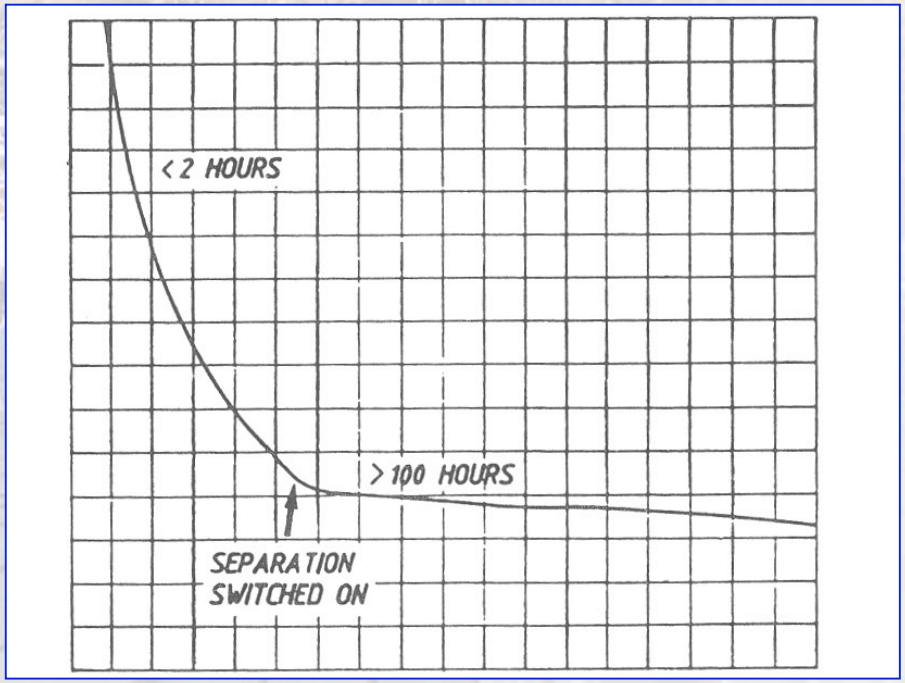
- Beam stability
- RF noise
- Intrabeam scattering
- Low-beta optics
- The beam-beam interaction.

The Beam – Beam Interaction

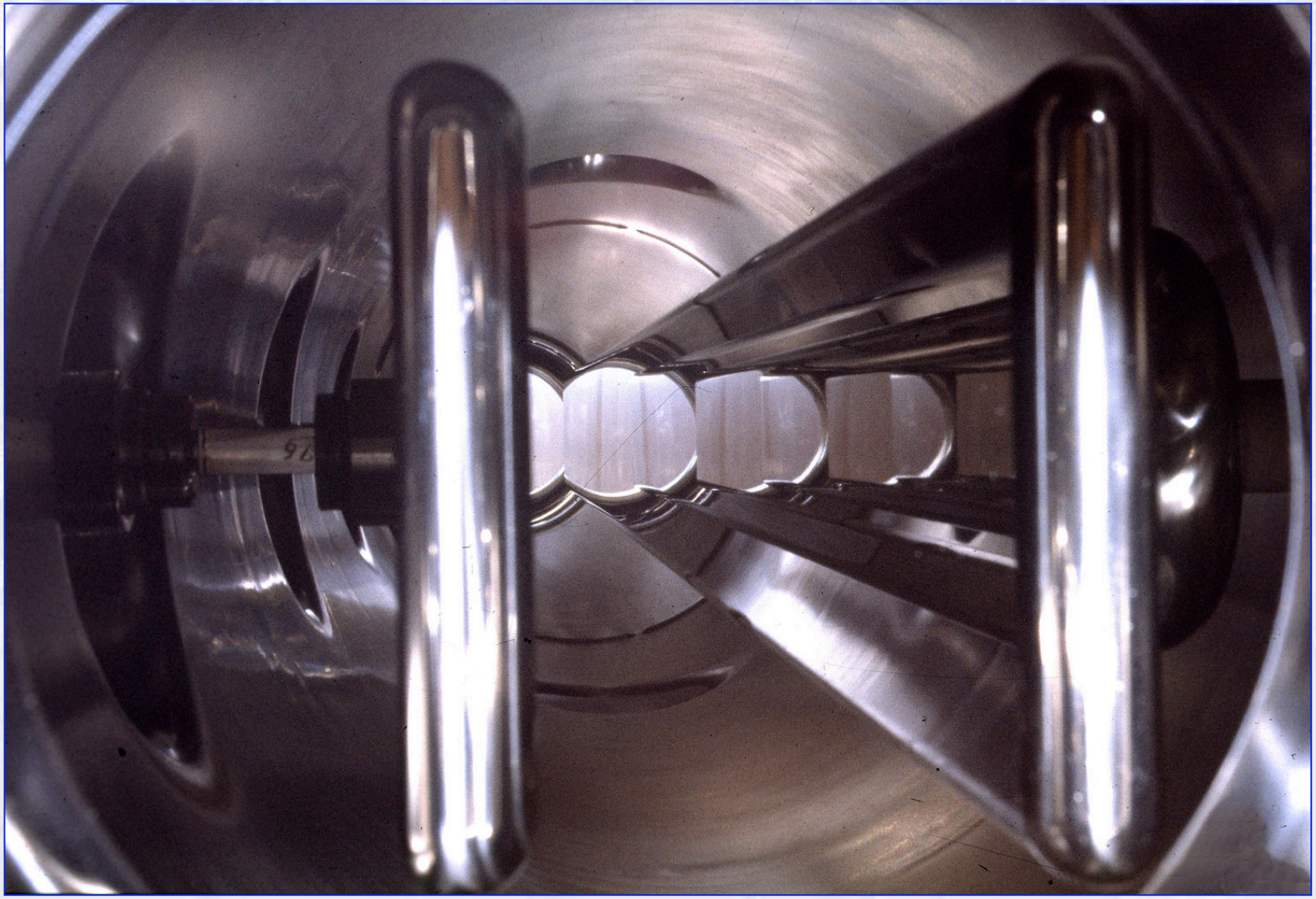


Beam Separation and Lifetime

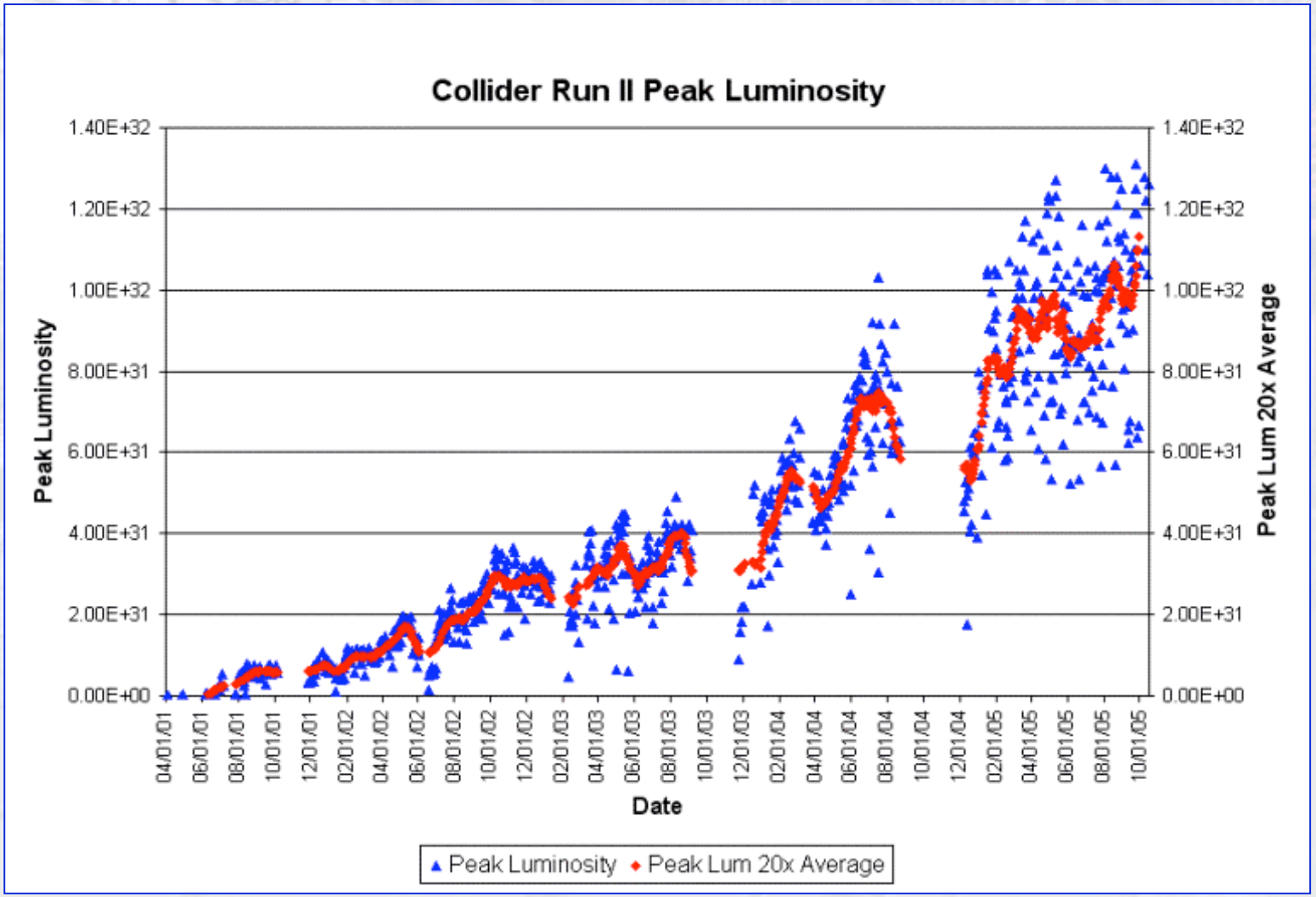




Electrostatic Separator



The Tevatron Luminosity Performance

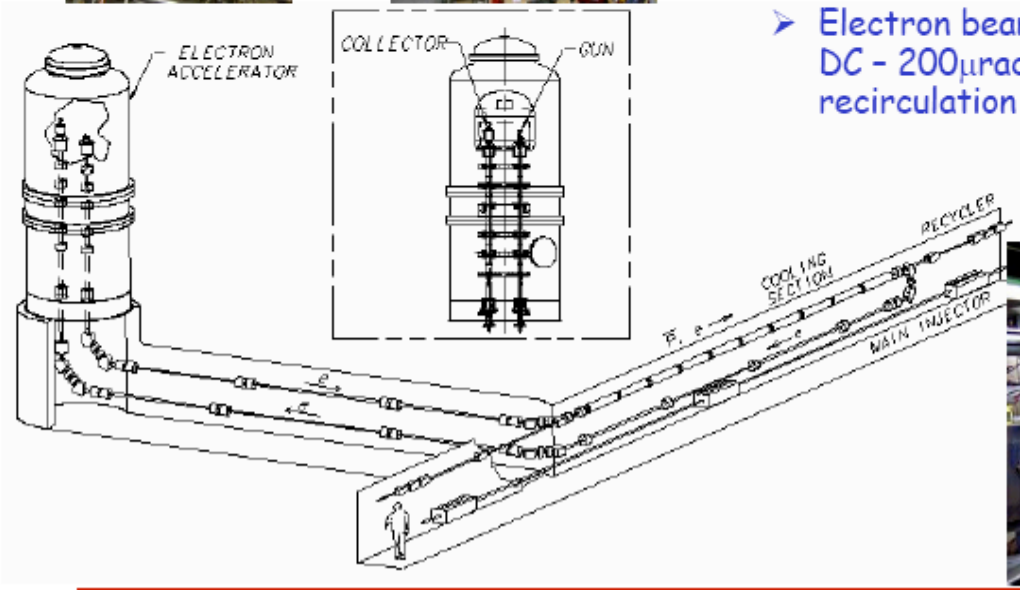


High Energy Electron Cooling

Fermilab
Accelerator Division

Recycler Electron Cooling

- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is being replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5 Amps DC – 200μrad beam spread – 99% recirculation efficiency

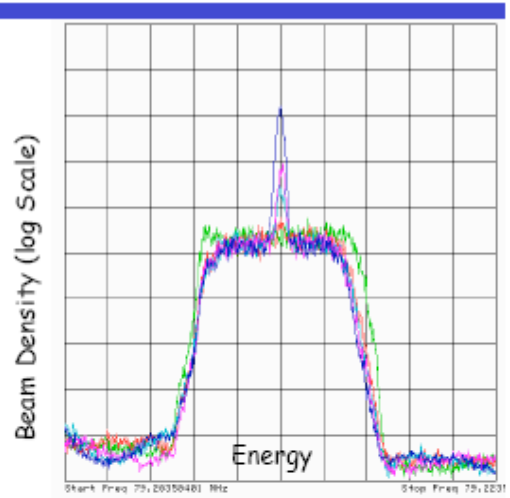


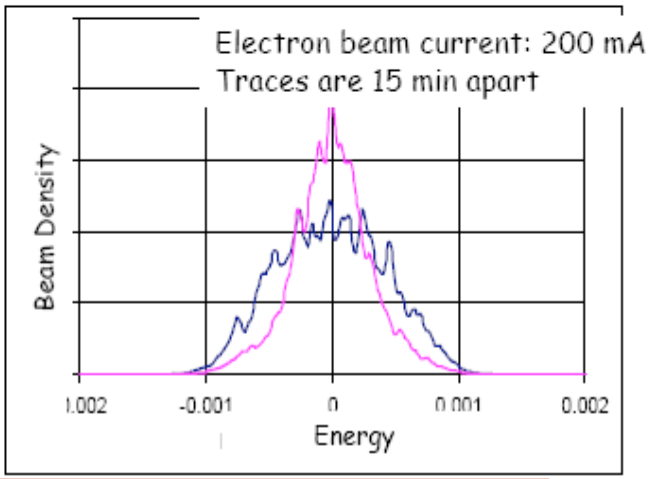
High Energy Electron Cooling

Fermilab
Accelerator Division

Recycler Electron Cooling

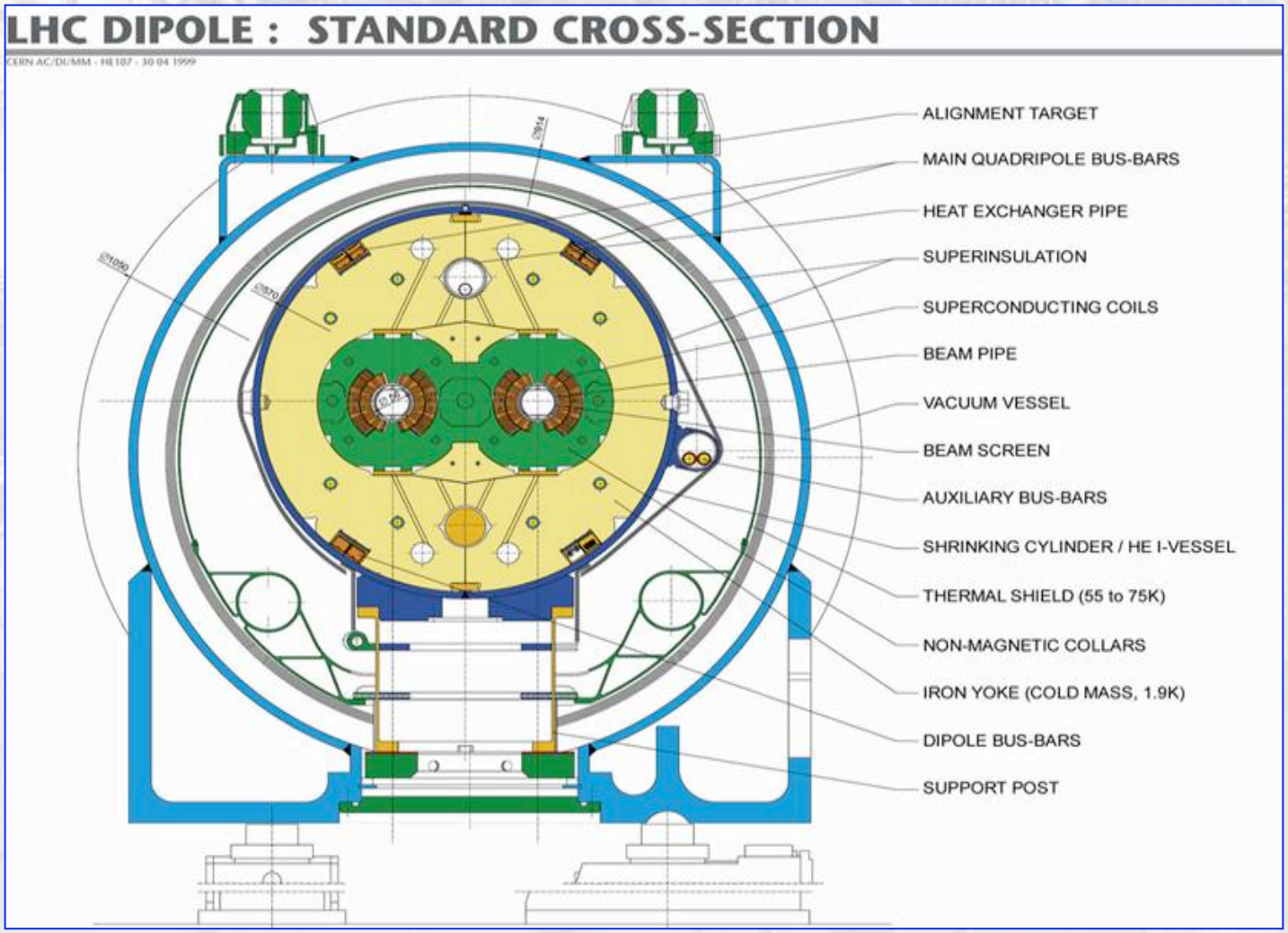
- Electron cooling commisioning
  - Electron cooling was demonstrated in July 2005 two months ahead of schedule.
  - By the end of August 2005, electron cooling was being used on every Tevatron shot
- Electron cooling goals
  - Can presently support final design goal of rapid transfers (30eV-Sec/2hrs)
  - Can presently reliably support stacks of 250×10^{10} (FY06 design goal)
  - Have achieved 500 mA of electron beam which is the final design goal.





The Large Hadron Collider

The Large Hadron Collider



The Large Hadron Collider

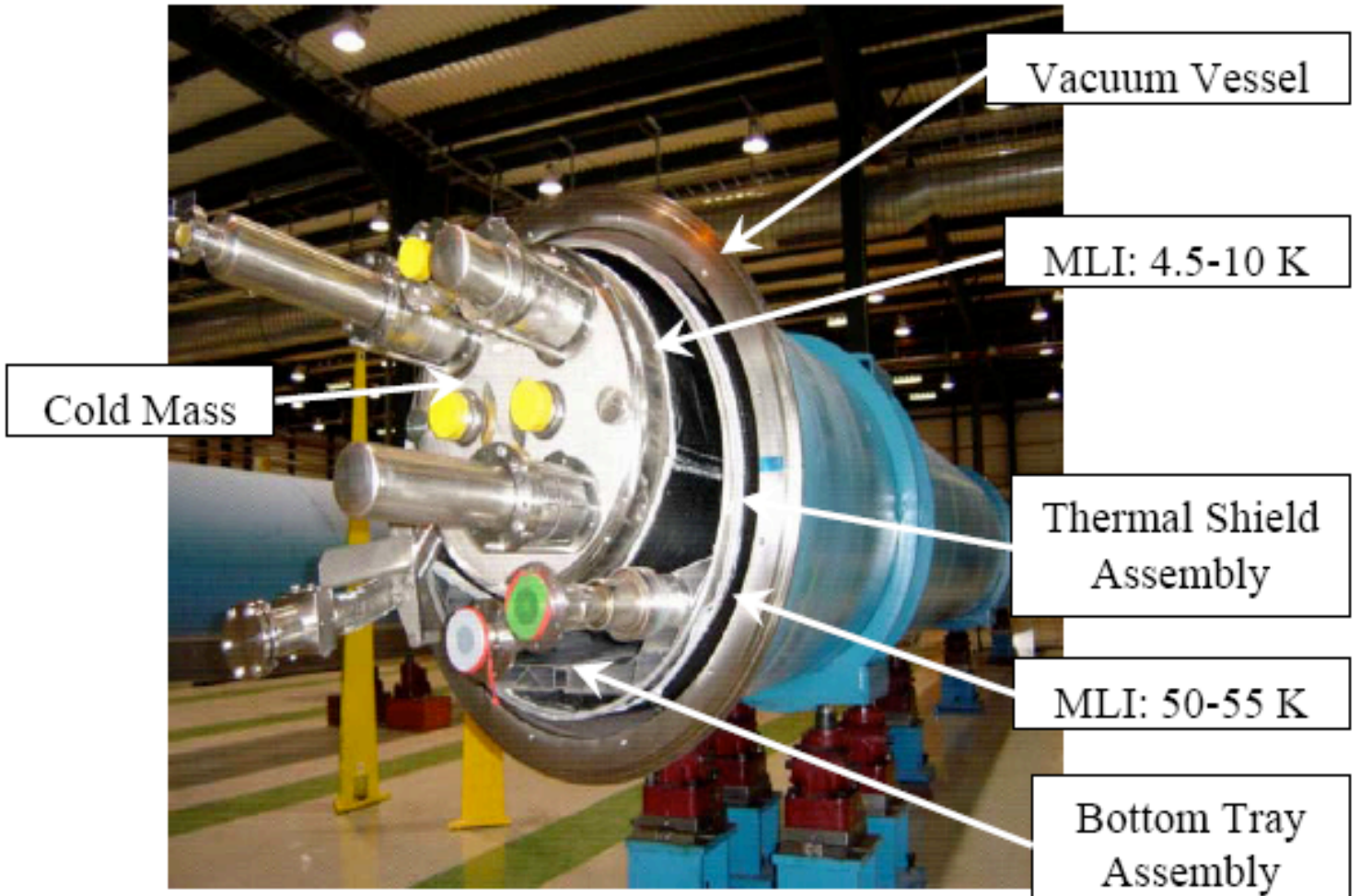


Figure 7.12: LHC dipole cryomagnet Assembly

Conclusions

- The developments leading to the successful conversion of the two high energy accelerators to proton - antiproton colliders has taken the art of manipulating and controlling particle beams to new heights.
- The lessons learned have been essential for the design of the LHC. However, due to the need for an increase of two orders magnitude in luminosity, the use of antiprotons is no longer an option. The final closure of the Tevatron collider will end an exciting and productive chapter in the development of accelerator technology.